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THE ULTIMATE CONSEQUENCES OF THE NEW GROWTH THEORY; AN INTRODUCTION TO THE VIEWS OF M. FITZGERALD SCOTT

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The Ultimate Consequences of the New Growth Theory; An Introduction to the Views of M. Fitzgerald Scott

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SUMMARY

The paper discusses traditional and new growth theories. It compares developments in this field with the views of M.F. Scott, who constructed a new growth theory independent of other recent contributions. It is shown that Scott's theory fits in with the existing framework. Substitution of an investment programme contour (IPC) for the neoclassical production function makes growth theory more flexible as it is no longer necessary to assume that technological change is labour-augmenting. It is demonstrated that an analysis based on the IPC can be extended in several directions.

JEL code: 110, 620

* I have benefited from comments by Frederick van der Ploeg, Anton van Schaik and Jacques Smulders. Of course, the usual disclaimer applies.

1. Introduction

A fresh look at the stylized facts of economic growth and a dissatisfaction with the traditional theory has led to a new interest in the theory of economic growth. Traditional theory is strongly rooted in a static view of the world. The neoclassical production function which takes a central position in the growth theory of the sixties is such a static concept. It assumes a blueprint of production possibilities with diminishing returns with respect to both factors of production labour and capital. Exogenous shocks in the form of a rise in population or an improvement in technical knowledge may overcome diminishing returns with respect to capital. If such shocks are of a continuous nature there may be permanent growth. Specifying technological change as pure labour augmenting opens the possibility of steady growth. Output and capital then increase at the natural rate of growth, which is the sum of population growth and the rate of labour augmenting technological change. The savings or investment rate has no long-run influence on the growth rate (e.g. Solow, 1970).

In the recently developed new growth theory these unsatisfactory results are removed. Technological change is now considered as man-made either because people devote resources to education or firms spend their money successfully on R&D (e.g. Romer, 1986, 1988; Lucas, 1988; Bean, 1990; King and Rebelo, 1990; Rebelo, 1990). In these studies capital accumulation is still subject to diminishing returns, but economic agents have the possibility to cope with this by raising labour efficiency. Extra savings set the mechanism of diminishing returns with respect to the production of commodities into operation. But it then pays to allocate additional resources to R&D and the like. As a consequence, the long-run rate of growth depends upon the savings rate in these models. Although this new growth theory, as it is named, is an improvement compared with the traditional theory, one could argue that it is a halfway house, because there is no reason to maintain the old house (called production function).

This brings us to the view of M. Fitzgerald Scott (1989) who argues that all accumulation of capital or rather all acts of investment are changing the world. It does not make sense to consider some investment projects as applications of existing blueprints whereas other activities are the fruit of research and education. In Scott's view investment not only is innovative but also opens new possibilities for profitable change. It is a remarkable coincidence that Scott's book, which had a gestation period of about ten years, is published at the time that a new growth theory flourishes in professional journals. However, the theoretical part of the book is certainly not a duplication of the work by Romer, Lucas and others. On the contrary, it extends the developments set in motion by the new growth theory.

In this paper we shall show just that. As a warning in advance it should be stressed that we do not intend to review Mr. Scott's book in the normal sense. It is our intention to cast his analysis in a modern mathematical language to make it comparable with modern developments referred to above. This may facilitate a discussion of the ultimate consequences of the new theory of economic growth, i.e. the cancellation of the neoclassical production function and the elimination of the sharp distinction between investment and innovation. Moreover, our reformulation of the model of Scott generalises the theory in certain respects, so that new applications may be stimulated. Accessibility and improvement may go hand in hand.

The organisation of the paper is as follows. Section 2 is devoted to a short survey of traditional growth theory cast in a modern form. Consumers are assumed to optimise over an infinite horizon given their intertemporal preferences and budget constraints. Producers or firms are maximizing the present value of the cash flow over an infinite horizon, taking into account the production possibilities and the factor prices. Competition is perfect and all markets clear. The new growth theory with its emphasis on R&D and similar activities is discussed in Section 3 within the same framework of optimizing agents. In Section 4 we present the theory of Scott along the (mathematical) lines set out in the previous sections. In addition, we derive comparative statics results for the steady-state solution of the model. To keep the whole within manageable bounds we shall mention but not discuss external effects, which are important in the new growth theory, but which are not essential for our purpose here. Moreover, traditional dynamics will be summarily dealt with, which reflects the state of knowledge on this point.

2. Traditional growth theory: manna from heaven

Traditional growth theory flourished in the sixties. Its main characteristics are well-known. The long-run growth rate of the economy is determined by the rate of population growth and exogenous technological change which has to be purely labour augmenting. To set the stage for our subsequent discussion it may be useful to present this theory in a formal way.

In the background of the theory of economic growth there is general equilibrium analysis. Consumers maximize an intertemporal utility function subject to an intertemporal budget constraint. Producers maximize the present value of the cash flow taking account of the production possibilities and the accumulation of capital. Prices on output and input markets are determined in fully competitive markets.

All consumers are alike and individual or per capita consumption is denoted by c_i. It is convenient to specify the intertemporal utility function in the following way

$$u = \int_0^\infty \left(\frac{1}{1-\beta}\right)[c_i(t)^{1-\beta}-1]\exp(-\alpha t)\, dt \tag{2.1}$$

where α is the constant rate of time preference and β is the constant (positively defined) elasticity of marginal instantaneous utility, which is usually referred to as the coefficient of (relative) risk aversion. Consumers maximize (2.1) subject to an intertemporal budget constraint, which could be written in general terms as

$$\dot{a}_i = ra_i - c_i \tag{2.2}$$

where a_i denotes total human and non-human wealth of individual i. Maximization of (2.1) subject to the constraint (2.2) yields the familiar first order condition

$$\beta \frac{\dot{c}_i}{c_i} = r - \alpha \tag{2.3}$$

Suppose that there are $\ell(t)$ consumers and that the number is growing at the rate g_ℓ. Denoting aggregate consumption by c we may write $\frac{\dot{c}}{c} = \frac{\dot{c}_i}{c_i} + g_\ell \equiv g$. Substituting in eq. (2.3) and rewriting the result gives the required rate of return:

$$r = \alpha + \beta(g-g_\ell) \tag{2.4}$$

Turning to producers we assume that production possibilities are represented by the function $f(k,h\ell)$ and goods market equilibrium by

$$y = c+i \tag{2.5}$$

where y is output, k is capital, ℓ is labour, h is labour efficiency and i is investment. Producers are price takers and maximize the present value of their cash flow subject to $\dot{k}=i$ (ignoring depreciation). This yields

$$f_\ell = w \quad \text{and} \quad f_k = r \tag{2.6}$$

where w denotes the real wage rate, so that the marginal product of factors of production equals their renumeration rate. Since there are no costs of adjustment, capital and labour can be adjusted immediately to the desired levels. Assuming as is usual in neoclassical theory, constant returns to scale one has

$$hF - \frac{k}{\ell} F' = \vartheta hF = w \quad \text{and} \quad F' = r$$

where $f\left(\frac{k}{h\ell},1\right) \equiv F\left(\frac{k}{h\ell}\right)$ denotes the intensive form of the production function and $\vartheta \equiv 1 - \frac{k}{h\ell}\frac{F'}{F}$ denotes the production elasticity of labour.

Now if labour increases at the constant rate g_ℓ and labour efficiency rises at the constant rate g_h, we have a balanced-growth solution with output, consumption, investment and capital rising at the rate $g \equiv g_\ell + g_h$. The real wage rate increases at the same rate as labour efficiency. The rate of interest is constant, $r=\alpha+\beta g_h$, and together with (2.6) yields a solution for the capital intensity $\xi \equiv k/h\ell$. As h and ℓ are exogenous variables, this result determines a unique long-run value for the level of the capital stock. As the growth rate is determined by exogenous factors the savings rate (σ) has no effect on the (long-run) growth rate. The savings rate is given by $\sigma \equiv \frac{i}{y} = \frac{\xi g}{F(\xi)}$. The dynamics of the model can be analysed by using a phase diagram for the state variables c and k. It is then easy to show that the system exhibits saddlepath stability (e.g. Blanchard and Fischer, 1989, Ch.2). However, transitional dynamics is not the main concern of the present paper, so that we refrain from working out the details.

A theory of economic growth which treats technological change as manna from heaven is unsatisfactory. To change production processes and to introduce new products effort and time is required. Firms spend money on R&D and people devote time to acquire new knowledge and additional skills. As a consequence there are important trade-offs with respect to the generation of technological change. This is the main theme of the new growth theory, which will be discussed in the next section.

3. The new growth theory: a halfway house

In the new growth theory as pioneered by Romer (1986) and Lucas (1988) the basic idea is that knowledge can be produced by foregoing current consumption. Labour efficiency, h, is made endogenous by assuming that firms or workers invest in the development of additional skills and new methods of production. There are different ways to model this fundamental notion. In Lucas (1988) consumers devote a fraction of their time to acquire new skills. Others assume that the production of knowledge requires both labour and capital as inputs (e.g. Bean, 1990; King and Rebelo, 1990; Romer, 1990). Usually, there are two sectors in such an economy. One sector produces goods, which can be consumed or invested. The other sector produces knowledge, which serves as an input in the sector producing goods. As stated in King and Rebelo (1990) the essential element of these models is that there is a "core" of capital goods which can be produced without the direct or indirect contribution of non-reproducible factors such as labour. To say it somewhat differently, the new growth models have Von Neumann features.

Whatever merits a distinction between goods-producing and knowledge-producing sectors may have it is not necessary to illustrate the main characteristics of the theory. The problem of sectors can be circumvented by assuming that producers use a fraction (ψ) of their own output for R&D. The engine of growth in our presentation of the new growth theory can then be specified by the function

$$g_h \equiv \frac{\dot{h}}{h} = m\ (\psi), \qquad m'>0, \quad m''<0 \tag{3.1}$$

It should be observed that the share of R&D explains the rate of growth of labour efficiency, which generates the "core" property referred to above.

The maximization problem of firms can now be stated as

$$\text{Max } v = {}_0\int^{\infty}[\{(1-\psi)f(k,h\ell) - \ell w - i\}\exp(-{}_0\int^{t}r(s)ds)]dt \tag{3.2}$$

subject to $\dot{k}=i$ and (3.1). The Hamiltonian for this problem is

$$H = \{(1-\psi)f(k,h\ell) - \ell w - i\} + \varphi_1 i + \varphi_2\ h\ m\ (\psi) \tag{3.2}$$

The first-order conditions with respect to ℓ, i (and φ_1) yield the familiar marginal productivity conditions:

$$(1-\psi)f_\ell=(1-\psi)\vartheta hF = w \tag{3.3}$$

$$(1-\psi)f_k = (1-\psi)F' = r \tag{3.4}$$

Differentiating the Hamiltonian with respect to the instrument variable ψ results in the first-order condition:

$$\frac{\partial H}{\partial \psi} = -f(k,h\ell) + \varphi_2\ h\ m'(\psi) = 0$$

which leads to

$$\varphi_2 = \frac{\ell F}{m'(\psi)} \tag{3.5}$$

For the costate variable, φ_2, related to the state variable h we get:

$$\dot{\varphi}_2 = (r-g_h)\ \varphi_2 - (1-\psi)f_h \tag{3.6}$$

Integration of (3.6) with respect to time results in:

$$\varphi_2 = {}_0\int^{\infty} [\{(1-\psi)f_h\} \exp(-{}_0\int^{t}[r(s)-g_h(s)]ds)]dt \tag{3.7}$$

As appears from equation (3.7) φ_2 measures the future flow of (net) marginal returns to labour efficiency discounted by the growth-corrected rate of interest. For the marginal product of labour efficiency we have: $f_h=\vartheta\ell F$.

Balanced growth solutions on which consumption, capital and labour productivity are growing at constant percentage rates are easily obtained. In the steady state F and ψ will be constant, so that differentiation of equation (3.5) gives

$$\frac{\dot{\varphi}_2}{\varphi_2} = g_\ell \tag{3.8}$$

Elimination of $\dot{\varphi}_2/\varphi_2$ between (3.6) and (3.8) and applying equation (2.4) yields an implicit solution for the growth rate of labour efficiency. An explicit solution can be obtained by assuming a linear engine of growth: $g_h=\mu\psi$ as in Lucas (1988). After some simple manipulations we get:

$$g_h = \frac{g_\ell-\alpha+\mu\vartheta}{\beta-(1-\vartheta)} \tag{3.9}$$

The rate g_h can not exceed the maximum feasible rate μ. This leads to the restriction $\beta>1-\frac{\alpha-g\ell}{\mu}$. Small values of β lead consumers to postpone consumption forever, because the linear engine of growth does not exhibit diminishing returns to the share of output devoted to R&D[1]. The steady state rate of growth now depends on preferences and on saving behaviour through α and β. A rise in the rate of time preference (α) or an increase in the coefficient of risk aversion (β) leads to a lower growth rate of the economy. An increase in population growth (g_ℓ) is matched by a rise in the growth rate of labour productivity (g_h). Finally, as observed in Lucas (1988) and Bean (1990) the model exhibits some form of <u>hysteresis</u>. From

1 A similar condition on β is stated in Lucas (1988).

equation (3.4) one can derive a steady-state solution for $\xi \equiv k/h\ell$, but now both k and h are state variables. The stock of physical capital can therefore not uniquely be determined as in the traditional growth model of Section 2. As a consequence an economy starting with relatively low levels of knowledge or human capital and physical capital will remain permanently below the levels of an initially richer economy, ceteris paribus. However, this result will not apply if account is taken of a catching-up effect for relatively poor countries. We come back to this point later.

The new theory of economic growth as it stands can be conceived as a halfway house towards a complete reconstruction. On the one hand the idea of technological change, which has to be brought about by investing in effort and time is stressed. On the other hand the traditional and basically static production function is maintained to explain the production of commodities. In a different approach it will be recognized that there is no more repetition or duplication of existing production processes if firms invest to grow. In such a view bygones are really bygones and past levels do not matter. It is this refreshing view of the world which will be the subject of the next section.

4. Growth theory reconstructed: no use for capital

4.1 The model

The sharp distinction between production of goods and production of new knowledge has been forcefully attacked in a seminal study by M. Fitzgerald Scott (1989). His view can be summarized by three propositions: (1) There is no need for a specific knowledge generating sector at least from the vantage point of growth theory, because inventing is a particular form of investment; (2) There are no diminishing returns with respect to capital as assumed in neoclassical theory. Investment opportunities are recreated by undertaking investment, at least for large sectors of the economy or the aggregate economy; (3) A competitive equilibrium can exist without assuming a neoclassical production function which is concave in its arguments.

If the production function is seen as a too static representation of reality something else should be given to replace it. In the analysis of

Scott this is done by introducing what may be called here an <u>inverted engine-of-growth function</u> (IEG), which relates the growth rate of output and the rate of growth of labour input to the investment ratio, which generates these growth rates. The IEG function can be written as

$$\sigma = F(g, g_{\ell}) \tag{4.1}$$

It generalizes the ideas behind the engine of growth function as discussed in Section 3[1]. The investment ratio indicates to what extent current consumption must be foregone to realize growth. But now different project can be chosen for a given level of σ. This can be shown by a two dimensional illustration of the IEG, which has some similarity with a map of isoquants in the static theory of production.

< insert Figure 1>

The curves marked by σ_1 and σ_2 give the menu of choice for a given investment ratio. Defensive investment leads to a selection of projects in the south-west region of Figure 1, with a relatively high rate of labour savings and a relatively low rate of output growth. Offensive investment projects are to be found in the north-east region. They are characterised by a fast rate of growth of output and also by a relatively high rate of employment growth. It seems reasonable to assume that the curves are concave, so that the marginal rate of substitution $\frac{dg}{dg_{\ell}}$ decreases. Moreover, a higher effort in terms of consumption foregone (larger σ) may lead to higher rates of growth as shown by the curve indicated by σ_2 in Figure 1. The curves can therefore be conceived as contour lines of equation (4.1). For illustrative reasons it will be assumed in this section that the IEG

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1 It should be noticed that the IEG differs from Kaldor's technical progress function by relating growth rates to the investment ratio. Kaldor (1957) postulates a relation between $(g-g_{\ell})$ and (g_k-g_{ℓ}), which in the linear case gives the same results as a Cobb-Douglas production function with autonomous technological change.

function is homogenous of the first degree. This implies that an increase in the investment ratio by the factor λ raises the possible growth rates by the same factor. The contour lines are related to each other by iso-elastic shifts along rays from the origin as shown by the dotted lines in Figure 1. In case of constant returns to the rate of investment both sides of equation (4.1) can be divided by σ, which gives the intensive form

$$1 = F\left[\frac{g}{\sigma}, \frac{g_{\ell}}{\sigma}\right] \tag{4.1a}$$

Equation (4.1a) can be rewritten as

$$\frac{g}{\sigma} = f\left[\frac{g_{\ell}}{\sigma}\right], \qquad f'>0, \quad f''<0 \tag{4.2}$$

This is the more compact representation of the possibilities for growth chosen in Scott (1989). It is there called the investment programme contour (IPC). The IPC has the same form as the contour lines of the IEG function as is illustrated in Figure 2. In the sequel we shall work with the IPC, because it incorporates the constant returns assumption and also because it facilitates a comparison with the original analysis of Scott.

< insert Figure 2 >

Firms are price takers and maximize the present value of the cash flow

$$v = {}_{0}\int^{\infty}[\{(1-\sigma)y-\ell w\} \exp(-{}_{0}\int^{t}r(s)ds)]dt \tag{4.3}$$

subject to the IPC in (4.2).

The Hamiltonian for the present maximization problem is

$$H = (1-\sigma)y - \ell w + \zeta\left[\frac{g}{\sigma}-f\left(\frac{g_{\ell}}{\sigma}\right)\right] + \varphi_1 g\, y + \varphi_2(g_w+g_{\ell})(\ell w) \tag{4.4}$$

where $g_w \equiv \dot{w}/w$. The letter ζ denotes a Lagrangian multiplier associated with the IPC and φ_1 and φ_2 are the costate variables associated with the state variables y and ℓ. The first order conditions can easily be derived as

$$\frac{\partial H}{\partial \sigma} = - y - \zeta \left[\frac{g}{\sigma^2} - f' \frac{g_\ell}{\sigma^2}\right] = 0 \tag{4.5}$$

$$\frac{\partial H}{\partial g} = \frac{1}{\sigma} \zeta + \varphi_1 y = 0 \tag{4.6}$$

$$\frac{\partial H}{\partial g_\ell} = - \frac{1}{\sigma} \zeta f' + \varphi_2 \ell w = 0 \tag{4.7}$$

Equations (4.5) and (4.6) can be combined to

$$\frac{g}{\sigma} - f' \frac{g_\ell}{\sigma} = \frac{1}{\varphi_1} \tag{4.8}$$

Similarly from equations (4.6) and (4.7) we get

$$f' = - \frac{\varphi_2}{\varphi_1} \lambda \tag{4.9}$$

where $\lambda \equiv \frac{\ell w}{y}$ denotes the share of wages in output. The rates of change of the costate variables φ_1 and φ_2 are given by

$$\dot{\varphi}_1 = (r-g)\ \varphi_1 - (1-\sigma) \tag{4.10}$$

$$\dot{\varphi}_2 = [r-(g_\ell+g_w)]\varphi_2 + 1 \tag{4.11}$$

As can be easily checked the model comprises the equations (4.2) and (4.8)-(4.11). Together with the definition for λ the model can be solved for the six endogenous variables: σ, g_ℓ, g, λ, φ_1 and φ_2, given initial conditions on output and employment. At this stage of the analysis the time paths of the interest rate, r, and the real wage rate, w, are exogenous.

In a steady state σ, g, g_ℓ and λ are constant. Moreover, for a fixed value of λ we must have: $g=g_w+g_\ell$. As appears then from equations (4.8) and

(4.9) a steady-state solution implies $\dot{\varphi}_1=\dot{\varphi}_2=0$. Therefore, in a situation of balanced growth the following conditions hold:

$$f' = \frac{\lambda}{1-\sigma} \tag{4.12}$$

$$\sigma r = g-\lambda g_{\ell} \tag{4.13}$$

Equations (4.2), (4.12) and (4.13) constitute a system of three equations in five unknown variables, viz. g, g_{ℓ}, σ, λ and r. To complete the macroeconomic model of a steady state we assume that employment increases at the given rate of population growth. This eliminates g_{ℓ} as an endogenous variable. Further, we assume that consumers maximize an intertemporal utility function subject to an intertemporal budget constraint as discussed in Section 2. This results in an additional equation for the (required) rate of return. The complete model now comprises the equations (2.4), (4.2), (4.12) and (4.13). An explicit solution for σ, λ, g and r is difficult to obtain even after specifying the IPC as the model is highly non-linear. However, comparative statics results can be found in a straightforward manner. Before working out the details we shall have a closer look at the equilibrium conditions (4.12) and (4.13), which correspond to the results derived by Scott (1989) for a situation of equilibrium or balanced growth in a more intuitive way.

Equation (4.12) implies that for a given investment ratio firms will select more labour saving projects as λ increases. A high value of λ leads to a comparatively more defensive investment strategy with a relatively low growth rate of output. This is illustrated in Figure 2 by a move from point B to point A. If g_{ℓ}/σ rises, so that labour becomes more abundant, the share of wages declines. In this case the shift is from point A to point B in Figure 2. These results make sense in a world governed by profit maximizing firms. Equation (4.13) can be conceived as a formula for the rate of return on investment. It shows that the rate of return is positively correlated with the growth rate of output and negatively with the rate of investment and the growth rate of labour weighted by the share of wages: $r=\frac{g-\lambda g_{\ell}}{\sigma}$. It is interesting to compare this result with a similar expression for the rate of return obtained from traditional growth theory which reads: $r=\frac{g-\lambda g}{\sigma}$. In the present theory the rate of return can be higher, because there is no need to assume that technological change is purely labour-augmenting as in the neoclassical theory[1]. This seems an important advantage of the IPC-model.

Turning to comparative statics we have to take total differentials. The resulting system can be written in matrix notation as

$$\begin{bmatrix} (1-\beta\sigma) & f'+\frac{1-\sigma}{\sigma^2} g_\ell f''-r \\ \sigma & g_\ell f'-g \end{bmatrix} \cdot \begin{bmatrix} dg \\ d\sigma \end{bmatrix} = \begin{bmatrix} \frac{1-\sigma}{\sigma} f''-\beta\sigma & \sigma \\ \sigma f' & 0 \end{bmatrix} \cdot \begin{bmatrix} dg_\ell \\ d\alpha \end{bmatrix} \tag{4.14}$$

To simplify we only consider the effects of a change in population growth (g_ℓ) and a change in the rate of time preference (α) on the endogenous variables g and σ. The impact of these changes on λ will be discussed afterwards. The solution of (4.14) is given by

$$\begin{bmatrix} dg \\ d\sigma \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} -(g-f'g_\ell)(\frac{1-\sigma}{\sigma} f''-\beta\sigma)-\sigma f'[f'(1-\frac{1-\sigma}{\sigma}\varepsilon)-r] & -\sigma(g-f'g_\ell) \\ -\sigma(\frac{1-\sigma}{\sigma} f'' - \beta\sigma) + (1-\beta\sigma)\sigma f' & -\sigma^2 \end{bmatrix} \cdot \begin{bmatrix} dg_\ell \\ d\alpha \end{bmatrix} \tag{4.15}$$

where the determinant $\Delta=-(1-\beta\sigma)(g-f'g_\ell)-\sigma\{f'(1-\frac{1-\sigma}{\sigma}\varepsilon)-r\}$ and $\varepsilon\equiv-\frac{f''}{f'}\frac{g_\ell}{\sigma}$ is the positively defined elasticity of the IPC. For a sufficiently high value of β the determinant will be positive. As in the previous section the condition on β can be relaxed if diminishing returns to the rate of investment are assumed. In the constant returns case β has to be relatively high to prevent consumers form postponing current consumption forever. If we make the not unreasonable assumption $\varepsilon < \frac{\sigma}{1-\sigma}$ a sufficient condition for the matrix to be positive is $\beta > \frac{1}{\sigma}$. For $\Delta>0$ the following results can be derived from (4.15):

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1 This was pointed out to me by Jacques Smulders. The neoclassical formula can be found by differentiating the adding-up relation $y=\ell w+kr$ with respect to time, taking account of r as a constant and $g_w=g_h$ in the steady state.

$$\frac{dg}{dg_{\ell}} > 0, \qquad \frac{d\sigma}{dg_{\ell}} > 0, \qquad \frac{dg}{d\alpha} < 0, \qquad \frac{d\sigma}{d\alpha} < 0 \tag{4.16}$$

A rise in population growth leads to a higher growth rate of the economy and to a higher rate of investment. An increase in the rate of time preference induces a lower growth rate and a lower rate of investment as may be expected. The effects on λ of changes in the exogenous variables can be deduced from equation (4.12). Total differentiation of (4.12) yields

$$d\lambda = [f'(\frac{1-\sigma}{\sigma}\varepsilon-1)]d\sigma + \frac{1-\sigma}{\sigma} f'' \, dg_{\ell} \tag{4.17}$$

Combining (4.16) and (4.17), recalling the assumption made earlier: $\varepsilon < \frac{\sigma}{1-\sigma}$, results in:

$$\frac{d\lambda}{dg_{\ell}} < 0, \qquad \frac{d\lambda}{d\alpha} > 0 \tag{4.18}$$

A rise in the growth rate of labour supply induces a fall in the share of wages. An increase in the rate of time preference causes a rise in the share of wages. It is interesting to notice that these results correspond to the outcomes of Post-Keynesian growth theory (e.g. Pasinetti, 1974), but the similarity is only superficial. Post-Keynesian growth theory is based on differential savings ratios out of wages and profits with the natural rate of growth determined by exogenous factors. A rise in the natural rate or a fall in savings ratios requires then an increase in the share of profits in the steady state. In Scott's model the share of profits rises as exogenous factors raise the profitability of relatively offensive as opposed to defensive investment opportunities.

4.2 Extensions

The model can be extended in several directions. A convenient way to do so is to introduce a shift in parameter q in the IPC:

$$\frac{g}{\sigma} q = f\left[\frac{g_{\ell}}{\sigma} q\right] \tag{4.19}$$

Changes in q the reciprocal of which is called the radius in Scott (1989) shift the IPC homothetically. The factor q may be related to variables inside or outside the model. For instance, it could be assumed that q depends on the rate of investment according to

$$q = q(\sigma), \qquad q'<0, \qquad q''>0 \tag{4.20}$$

Equation (4.20) in combination with equation (4.19) implies diminishing returns with respect to the rate of investment. As σ increases it becomes progressively more difficult to realize higher rates of economic growth. The consequences for the rate of return are discussed in Scott applying a specification of (4.20).

Here we shall use the device to analyse the effect of productive government spending on the engine of growth. Government spending on cooperative R&D increases the growth rates which would otherwise be realized by the private sector. The same may be true for the categories of spending which improve the infrastructure of the economy and so facilitate the innovating activities of firms. Denoting the share of productive government spending in output by γ equation (4.20) can then be replaced by

$$q = q(\gamma), \qquad q'>0, \qquad q''<0 \tag{4.21}$$

The government runs a balanced budget, but taxation does not interfere with the decisions of the private sector (taxes are either lump-sum or are levied on rents). A natural efficiency condition for government outlays can be found by assuming that the present value Hamiltonian is maximized with respect to γ. Substituting (4.19) and (4.21) in equation (4.4) and substracting government expenditure gives:

$$H = \zeta[\frac{g}{\sigma}\, q(\gamma) - f(\frac{g_\ell}{\sigma}\, q(\gamma))] - \gamma y \; ... \tag{4.22}$$

where the other terms of (4.4) are omitted to simplify the exposition. The first order condition for productive government spending is

$$\frac{\partial H}{\partial \gamma} = \zeta(\frac{g}{\sigma} - f'\frac{g_\ell}{\sigma})\; q'(\gamma) - y = 0 \tag{4.23}$$

Combining this condition with the first order conditions for the private sector yields

$$\frac{1}{q'(\gamma)} = \sigma \tag{4.24}$$

The reciprocal relation between γ and σ in the optimum situation makes sense if one realizes that the higher the contribution of the government to R&D the lower can be the efforts of the private sector to raise the growth rate of the economy. The growth rate depends on productive government spending as in Barro and Sala i Martin (1990), where the marginal product of capital is a function of γ.

The example shows that the radius construction is very flexible and can be applied to a number of other issues. For instance, positive externalities which may be all around in a dynamic world of innovating and learning agents can be handled by assuming that there is a positive connection between q and σ which is not internalised by profit maximising firms. Such externalities may motivate government intervention in the form of subsidizing private R&D on investment to attain a Pareto optimal outcome. There is, however, another side to the coin. Private sector activities may lead to congestion of the public services (e.g. Barro and Sala i Martin, 1990). In that case there is a negative external effect, which warrants taxation of private sector investment. Congestion effects can be build into the model by replacing equation (4.21) by: $q=q(\gamma,\sigma)$ with derivatives $q_1>0$, $q_2<0$. We shall not pursue this question here any further.

Returning to the original model the problem of the stability of a steady-state equilibrium has still to be resolved. However, as it stands the model is not complete in a dynamic sense. There is no equation telling how real wages move outside the steady state. This is a consequence of the fact that the model does not explain levels. There is full hysteresis: the level of output, employment and real wages is completely path-dependent. The theory explains rates of change. Against this background changes in $\lambda(=g_\ell+g_w-g)$ could be explained by the discrepancy between employment growth and the exogenous growth of labour supply (g_n), for instance

$$\frac{\dot{\lambda}}{\lambda} = \vartheta(g_\ell-g_n) \tag{4.25}$$

Equation (4.25) introduces an element of arbitrairness with respect to the adjustment path, but λ may converge to its steady-state value. Whether under this assumption the model is stable remains to be seen. Analytical results may be difficult to obtain, but numerical simulation could give some indication with respect to stability. However, such exercises must wait for another occasion.

5. Conclusions

The renewed interest in the theory of endogenous technological change has led to a number of models, which differ in their approach of the innovating process. However, most models can be characterised as a halfway house because of their sharp distinction between a commodity producing sector and a sector generating new knowledge. In a recent study Scott (1989) follows a more consequent approach by assuming that investment and technological change are inseparable. As a result there is no need for diminishing returns to capital accumulation and the neoclassical production function is removed from the stage.

The question to be asked is whether the new view of Scott is an improvement on the way to a better understanding of the process of economic growth. The answer should be based on the empirical significance of the theory. As shown in the book the theory does rather well in a number of empirical questions. But the same may be true of the alternatives referred to above. A final judgement should therefore include other considerations as well.

Substitution of the investment programme contour (IPC) for the neoclassical production function gives the model greater flexibility with respect to the bias of technological change. It is no longer necessary to assume that the change is purely labour augmenting as in the neoclassical theory. Moreover, an analysis cast in terms of the IPC can handle all relevant macroeconomic problems in an adequate way, with one exception. The model does not give information about the labour market outside the steady state. To analyse the transition process the model must be supplemented by an ad-hoc relation for the rate of change of the income distribution. Whether this is a drawback remains to be seen. Hysteresis phenomena are important in the new growth models which complicates their transitional dynamics. Here again the analysis of Scott marks an ultimate consequence of the new view: the level of employment (and therefore unemployment) is also path dependent.

Finally, to place Scott's theory into proper perspective two observations are in order. First, the model can be conceived as a representation of the dynamic or primary sector of the economy. This sector has to be supplemented by a labour-absorbing dual sector to deal with problems of employment and unemployment (e.g. Van de Klundert, 1990). Second, an analysis in terms of choices to be made between growth rates may be well suited to study economic development as pointed out long ago by Haavelmo (1954) in a contribution to the theory of economic evolution.

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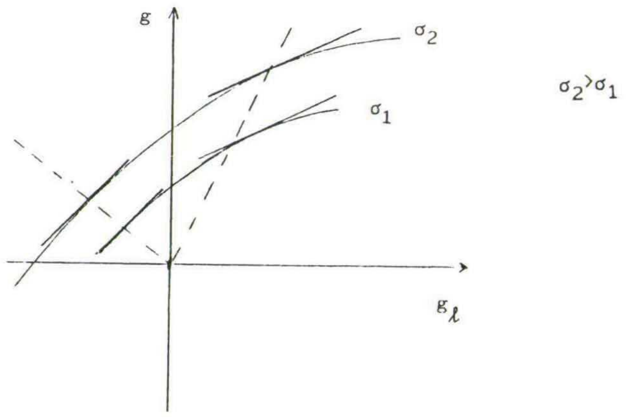

Figure 1

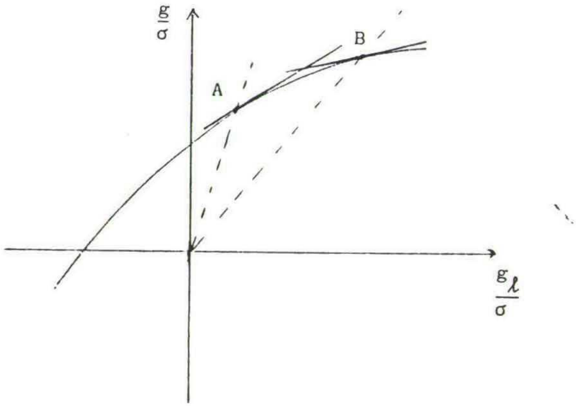

Figure 2

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